EXHIBIT AA

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Pathology of Explanted Transvaginal Meshes

Vladimir V. Iakovlev, Erin T. Carey, John Steege

***Abstract*—**The use of polypropylene mesh devices for Pelvic Organ Prolapse (POP) spread rapidly during the last decade, yet our knowledge of the mesh-tissue interaction is far from complete. We aimed to perform a thorough pathological examination of explanted POP meshes and describe findings that may explain mechanisms of complications resulting in product excision. We report a spectrum of important findings, including nerve ingrowth, mesh deformation, involvement of detrusor muscle with neural ganglia, and polypropylene degradation. Analysis of these findings may improve and guide future treatment strategies.

***Keywords*—**Transvaginal, mesh, nerves, polypropylene degradation.

I. Introduction

POLYPROPYLENE monofilament mesh was introduced for the treatment of pelvic organ prolapse relatively recently. The use of the devices spread rapidly, followed by a steady rate of complications resulting in excisions [1]-[10]. The excised specimens provide valuable medium to study the mechanisms of complications, yet most specimens are given "gross only" or very superficial microscopic examination [11]. Our aim was to perform detailed macro- and microscopic examination of explanted devices and analyze the findings together with the clinical symptoms, which prompted excision.

II. Material and Methods

After approval by the St. Michael's Hospital Research Ethics board, all specimens of POP explants received at the Pathology Department between January 2010 and April 2014 were retrieved retrospectively. In total, 24 specimens of St. Michael's Hospital patients and external consultation cases from litigation processes have been analyzed. The clinical records were reviewed to obtain information regarding complications and reasons for excision.

The specimens were received in 10% neutral buffered formalin, fixed for at least 48 hours and processed according to the laboratory standard operating procedures: gross examination to assess shape, size and texture; sampling for microscopic examination; paraffin embedding; sectioning at 4μm, staining with hematoxylin and eosin (H&E), immunoperoxidase stain for S100 protein (DAKO clone Z0311, enzyme digestion for 4 minutes, incubation for 16 minutes, 1:1000 dilution) and Alpha Smooth Muscle Actin (Dako clone 1A4, CC1 retrieval for 36 minutes, incubation for 16 minutes, 1:400 dilution) using Inview Ventana detection system and Ventana Benchmark XT.

The stained slides were assessed in regular and polarized light.

V. V. Iakovlev is with the Department of Pathology, St. Michael's Hospital and Keenan research Centre of the Li Ka Shing Knowledge Institute, University of Toronto, Toronto, Canada (e-mail: iakovlev.v@gmail.com).

E. T. Carey is with the Center for Pelvic Pain and Sexual Health, Department of Obstetrics and Gynecology, University of Kansas, Kansas City, USA.

J. Steege is with the Advanced Laparoscopy and Pelvic Pain, Department of Obstetrics and Gynecology, University of North Carolina, Chapel Hill, USA.

III. Results

Median patient age was 55 (range 47-72). Available clinical records indicated mucosal exposure as a reason for excision in 67% of cases, pain in 56%, and both in 33% of patients. Average *in vivo* time since implantation before excision was 2.4 years (range 0.7-5years). The devices were of three different manufacturers, where 15 were combination of lightweight and heavyweight meshes, and remaining 9 of all heavyweight design.

One specimen was received as one intact excision, while the remaining 23 were received in fragments with fragment size ranging from 0.4 to 12.0cm. For 21(87%) patients the samples were available in formalin for gross comparative assessment. Grossly the explanted meshes were described as firm. Subjectively, by palpation, the explanted lightweight meshes felt softer than the heavyweight designs, while both were firmer than either a new mesh or vaginal tissue excised during non-mesh surgeries. Of all specimens, 14 (58%) were received in fragments large enough to assess for gross deformations, which ranged from mild banding to more complex folding and edge curling.

Microscopically, all (100%) meshes were invested with collagenous scar, with chronic and foreign body inflammatory reaction. The large pores of the lightweight meshes had wider gaps, which were focally (up to 30% of mesh area) filled with loose connective tissue, however larger stretches (60% and more of the total explanted mesh) were filled with collagenous scar. The smaller pores surrounding the large pores in the lightweight meshes were uniformly filled with scar tissue. The heavyweight meshes had near complete scar encapsulation with only occasional individual pores showing loose connective tissue. Both designs displayed the ability to fold, curl edges and form more complex deformation, where the lightweight meshes had more complex deformation patterns.

Figs. 2 (a) and (b) show mesh filaments, which are clear in regular light and appear as empty holes in the sections. The images demonstrate the most complex patterns of deformations. Collagenous scar tissue stains solid dark pink by eosin. Note, that the deformations are fused *in vivo* by the scar. Clusters of dark blue staining reflect inflammatory reaction, which accompanies the mesh filaments.

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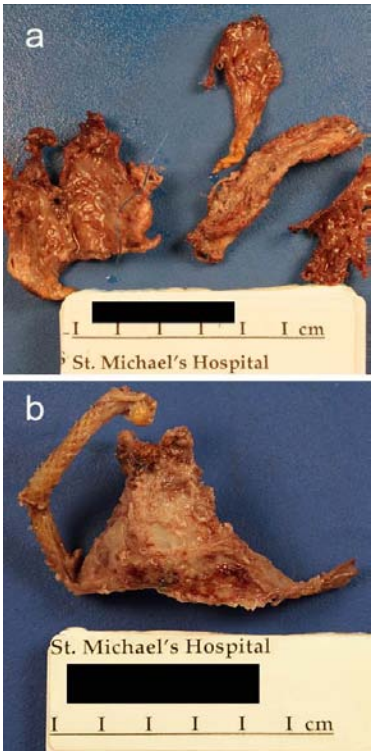

Fig. 1 Examples of gross appearance and deformations of explanted meshes (a) all lightweight, (b) arms are of heavyweight design

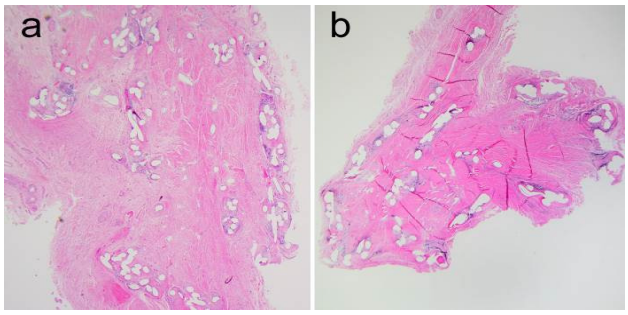

Fig. 2 Mesh deformation seen in histological slides. Low power, 2.5x objective, H&E (a) lightweight and (b) heavyweight mesh

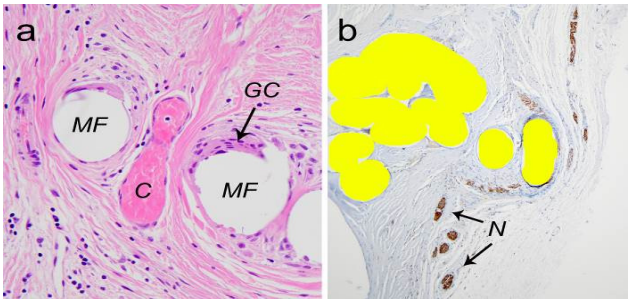

Fig. 3 Capillaries and nerve branches ingrown into the mesh structure (a) H&E, 20x objective, (b) S100 stain to highlight nerve branches, 10x objective

The spaces between filaments were introduced into the body with the mesh. They were filled with living tissue, including vascular network necessary for blood supply. We detected abundant capillaries in the scar within the mesh structures. Additionally, all meshes had nerve braches ingrown into the pores and deformation pockets. The nerves could be seen by H&E and S100 stain highlighting myelinating Schwann cells of the nerve branches.

Fig. 3 (a) shows a capillary (labeled *"C"*) with a very tight fit between two mesh filaments (*"MF"*). Cross sections of the filaments are left clear in the image. Note foreign body giant cells (*"GC"*) at the filaments.

In Fig. 3 (b) the filaments are filled yellow and the nerve branches are stained dark brown by S100 stain (two nerves pointed by arrows and *"N"*). In this image a small nerve bundle or a nerve with separated fascicles is interrupted by the mesh filaments. There is a noticeable distortion of one nerve branch/fascicle. In most cases the nerves appear healthy indicating that they can deliver sensory and motor signals of mixed somatic nerves.

Sufficiently large specimens (19 cases, 79%) showed presence of smooth muscle, either in thin strands consistent with vaginal wall origin, or in thick bundles indicating detrusor muscle involvement as shown in Fig. 4 (a).

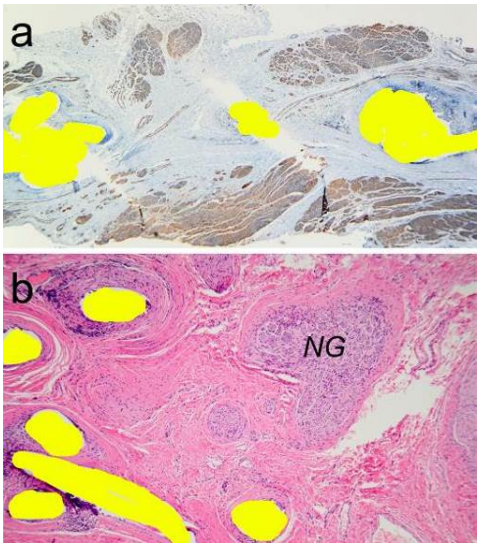

Fig. 4 Mesh involvement of the detrusor muscle and neural ganglia (a) Smooth muscle actin stain, 2.5x objective, (b) H&E, 20x objective

In Fig. 4 (a) smooth muscle is stained dark brown. The muscle is in thick bundles, which, at the location of the mesh indicates detrusor muscle involvement. In this position, deep in the muscle the mesh is expected to act as a rebar interfering with the muscle function.

In 2 (8%) cases there was involvement of neural ganglia detected in the sections. Fig. 4 (b) shows a neural ganglion labeled *"NG"*. The mesh can migrate through tissue and affect the structures on the path of migration.

A stand-alone finding was the detection of polypropylene degradation. The filaments in all (100%) of both lightweight and heavyweight designs showed a layer of homogeneous material surrounding the filaments. The material stained purple by H&E stain, which was different from the clear filament core. To test if the material is synthetic the sections

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were examined in polarized light. Both the core and the outer layer showed the same optical properties in polarized light. These findings indicated that the layer is degraded polypropylene.

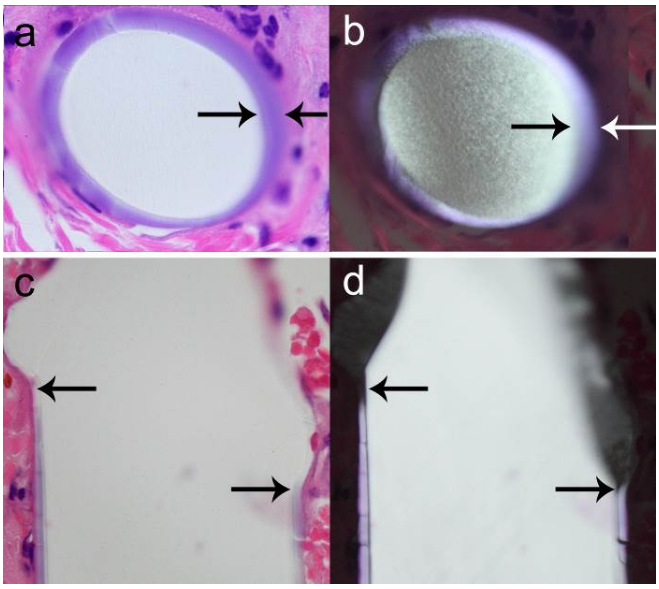

Fig. 5 Polypropylene degradation. The upper panels, (a) and (b) are photographs of the same lightweight filament taken in regular (a) and polarized light (b), filament is sectioned perpendicular to its length. The lower panel, (c) and (d) are of a heavyweight filament, in regular (c) and polarized light (d), filament sectioned along its length

The degradation layer resembled a tree bark: it surrounded the filaments and showed cracking and partial detachment from the core. In the upper images of Figs. 5 (a) and (b) the bark is shown between arrows. In regular light photographed in Fig 5 (a) the degraded material has purple color since it retains the dyes due to its porosity. In polarized light shown in Fig. 5 (b) the bark exhibits the same polarizing properties as the non-degraded central core. Note that human tissue cannot polarize light to the same degree and appears dark.

A feature indicating that the bark formed *in vivo* was finding of melted sites caused by electrocautery. Electrocautery is used during excisions and causes focal melting of polypropylene, including the degradation bark. Figs. 5 (c) and (d) show the transition point between the melted and intact material marked by arrows. Note that the bark lost its ability to retain dyes and melted together with the central core material. This finding indicated that the bark formed *in vivo*.

To exclude chemical processing artefacts, a control sample of a new mesh was kept in formalin for one month. Then the sample was subjected to all routine procedures of tissue processing and staining as the explant specimens. There was no detectable bark in the control sample.

IV. Discussion

While the long term interaction between the mesh and human tissue is insufficiently studied, our analysis demonstrates several features which can contribute to our understanding of the mechanisms of complications. The main reasons for mesh excision reported in the literature are mucosal exposure, pain with dyspareunia, and de-novo or worsening urinary symptoms [1]-[10]. The most important finding relating to the mechanism of pain was the presence of ingrown nerves in the mesh. The mesh introduces multiple compartments formed by pores and deformation pockets, which become filled by live tissue with a supply of nerve branches and vessels [12]. The innervated tissue can be exposed to a variety of possible pain initiators such as inflammation (which was present in all explants regardless of mucosal exposure), nerve entrapment, compression/stretching, edema, ischemia etc. The roles of these mechanisms need to be further studied.

The novel finding of detection of polypropylene degradation in histological sections is interesting, as polypropylene meshes have been in surgical use since late 50's, and have been regarded as inert. Previous descriptions of cracked surface detected by scanning electron microscopy have been challenged. The degradation bark is easily visible by routine microscopy, yet escaped pathologists for over 50 years. This situation shows a disconnect among pathologists, clinicians and manufacturers. As pointed out earlier, there is a general lack of interest in the mesh specimens in the pathology departments [11]. Polypropylene degradation may play a role in the continuous inflammatory response, mesh hardening and late deformations. Also, chemical products of degradation need to be studied for their composition and effect on the tissue.

We observed mesh migration into the bladder wall at the level of detrusor muscle. This indicates that the involvement may not be apparent clinically without erosion through the urothelial mucosa, but still may be symptomatic since the mesh interferes with the functional components of bladder wall: muscle, nerves and neural ganglia. We detected involvement of neural ganglia in 8% of cases, which can be an underestimation due to sampling of the small structures. The relationship between the mesh involvement of the bladder wall components and clinical symptoms needs to be studied further in detail.

Our analysis shows a spectrum of previously unreported findings, which indicates the overlooked value of studying explanted mesh material. We believe that these specimens contain information of the mechanisms of complications and further study may help guide future development of treatment modalities.

Disclosure

Authors provided medico-legal consultations on the subject.

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